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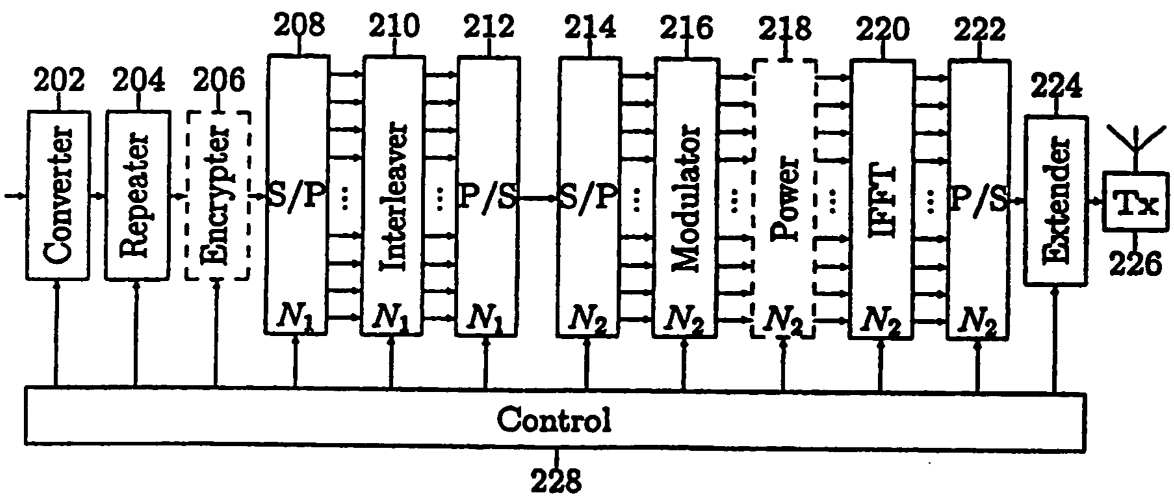

(57) Abstract

A method of operating a radio communication system uses multicarrier modulation for transmission of data between two or more stations. In the transmitter, multiple copies of parts of an input data stream can be generated by a repeater (204) to enable the application of variable degrees of diversity to different parts of the data. The diversity is applied by controlling the algorithm used by an interleaver (210) before the data is modulated (216), placed onto multiple carriers by an inverse fast Fourier transform (220) and transmitted (226). In the receiver, the multiple carriers are received (302), data is recovered from all the carriers by a fast Fourier transform (308) then demodulated (310). A de-interleaver (316) is controlled to use the same algorithm as the transmitter, copies of parts of the data stream are recombined (322) and an output bitstream is generated.

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DESCRIPTION

RADIO COMMUNICATION SYSTEM

Technical Field

The present invention relates to radio communication systems employing multicarrier modulation techniques. Such systems may carry audio or data channels, or a combination of the two.

Background Art

MultiCarrier Modulation (MCM), also known as Orthogonal Frequency Division Multiplexing (OFDM) or Discrete Multitone Modulation (DMT), is a technique by which data is transmitted at a high rate by modulating several low bit rate carriers in parallel, rather than one high bit rate carrier. MCM is spectrally efficient, and has been shown to be effective for high performance digital radio links. Possible application areas include Digital Audio Broadcasting (DAB) (for high quality audio signals), Wireless Asynchronous Transfer Mode (WATM), for high speed, short distance radio links between computer systems) and future mobile radio systems such as Universal Mobile Telecommunication System (UMTS).

A major problem with transmitting at high data rates is multipath propagation, where signals arrive at a receiver via different transmission routes. This can cause fading (where the signals destructively interfere) or inter-symbol interference (where one signal is delayed relative to another). MCM can overcome many of the problems caused by multipath propagation by its inherently greater robustness to noise and delay.

However, even with use of MCM some problems remain. A deep fade may affect one or more of the carriers for long enough to lose some data and so to maintain data integrity redundancy can be introduced into the system. One means for doing this is known as diversity, with four basic forms:

1. space diversity – using two or more antennas, with the intention

of reducing the chance of a fade affecting them all simultaneously;

2. time diversity – transmitting one or more additional copies of the data with a time delay between the copies, with the intention of reducing the chance of a time-varying fade affecting them all;

3. frequency diversity – transmitting on two or more frequencies, with the intention of reducing the chances of a fade affecting all frequencies simultaneously; and

4. coding diversity – adding an error correction code to the data. Although only one copy of the encoded data is transmitted, enough extra information has been encoded to cope with temporary loss of data.

US Patent Specification 5,283,780 describes an extension of coding diversity and is concerned with transmission of a number of audio channels in parallel. Each channel has error correction coding added, and is then regularly switched from one carrier to the next, so that any frequency selective fade only affects a small part of the transmitted data for each channel.

Both direct repetition of data and the addition of error coding have the disadvantage of increasing the bandwidth required to transmit the data.

Disclosure of Invention

An object of the present invention is to improve the performance of multicarrier systems.

According to one aspect of the present invention there is provided a method of operating a radio communication system using multicarrier modulation for transmission of data between two or more stations with one of said stations providing a data stream comprising a plurality of parts, characterised by applying different forms of diversity to at least two of said parts, the choice of diversity measures being made dynamically in response to the importance of the data or the quality of the transmission channel.

According to a second aspect of the present invention there is provided a transmitter comprising conversion means for converting an input bitstream into symbols, repetition means for generating one or more copies of each input

symbol, interleaving means for reordering the symbols in a data stream, modulation means for generating a data stream suitable for transmission over a radio channel, means for generating modulated carriers at multiple frequencies and transmission means, characterised in that means are provided for dynamically varying applied diversity measures in response to the importance of the data or the quality of the transmission channel.

According to a third aspect of the present invention there is provided a receiver comprising reception means for receiving signals at multiple frequencies, means for extracting modulated data from modulated carriers at multiple frequencies, demodulation means for extracting a data stream from the transmitted data, de-interleaving means for reordering the symbols in the data stream, combining means for generating one output symbol from one or more transmitted copies of a symbol and conversion means for generating an output bitstream from the symbol stream, characterised in that means are provided for dynamically varying applied diversity measures to correspond to those used for transmission.

The present invention is based upon the recognition, not present in the prior art, that not all data being transmitted requires the same degree of protection, so that a system implementing variable diversity is desirable.

By means of the present invention a radio communication system using multicarrier modulation can have diversity applied variably to the component parts of the data to be transmitted, for example depending on the importance of the information being transmitted and the state of the radio channel

Brief Description of Drawings

The present invention will now be described, by way of example, with reference to the accompanying drawings, wherein:

Figure 1 is a block schematic diagram of a system in accordance with the present invention;

Figure 2 is a block schematic diagram of an embodiment of a transmitter made in accordance with the present invention;

Figure 3 is a block schematic diagram of an embodiment of a receiver made in accordance with the present invention;

Modes for Carrying out the Invention

The system shown in Figure 1 comprises two stations 102, 104, each containing a transceiver, with a two-way radio communication link between them.

The transmitter shown in Figure 2 processes an input bitstream and broadcasts it using a MCM technique. The input bitstream comprises the data to be transmitted, and may optionally have had an error correction code applied to it for enhanced robustness. This bitstream is first presented to a converter 202, which generates the required stream of input symbols for further processing. A control block 228 ensures that the input symbols generated are appropriate to the modulation scheme being used for transmission, for example 2 bit symbols if Quadrature Phase Shift Keying (QPSK) is to be used. The control block may also add information to the data stream detailing how diversity has been applied.

A symbol repeater 204 takes this stream of input symbols and outputs each symbol one or more times, under instruction from the control block 228 (thus giving the possibility of different amounts of diversity for different parts of the data stream). If required, for security reasons, the stream of input symbols may be encrypted by an optional encryption block 206 which, if present, operates under instruction from the control block 228.

A multiplexer 208 takes as an input a serial stream of N_1 symbols and outputs each symbol onto one of its N_1 parallel output lines. The control block 228 may alter the block size so that the stream comprises fewer than N_1 symbols so that fewer output lines are required. An interleaver 210, under instruction from the control block 228, reorders the symbols and applies them to its output data lines. These output symbols are then recombined into a serial stream by a demultiplexer 212.

Next a multiplexer 214 takes as an input a serial stream of N_2 symbols

and outputs each symbol onto one of its N_2 parallel output lines. The control block 228 may alter the block size so that the stream comprises fewer than N_2 symbols so that fewer output lines are required. Note that if $N_1=N_2$ the demultiplexer 212 and multiplexer 214 may both be omitted.

The symbols on each of the output data lines from the multiplexer 214 (or the interleaver 210 if $N_1=N_2$) are then modulated by a modulator 216, where the method of modulation (e.g. QPSK) is controlled by the control block 228 which ensures it is appropriate for the symbols generated by the converter 202. If required, for example in a system serving multiple users at different distances from the transmitter, the power level that will be used to transmit each symbol can be adjusted by an optional power controller block 218. The modulated data is then inverse fast Fourier-transformed by an IFFT block 220 before being recombined into a serial data stream by a demultiplexer 222.

Before the data stream is suitable for transmission, cyclic extension (also known as a guard interval) is added and pulse shaping is performed by a symbol extender block 224, with the aim of avoiding inter-symbol interference. The techniques used by the symbol extender block 224 are well known, as described for example in "Principles of Modulation and Channel Coding for Digital Broadcasting for Mobile Receivers" M. Alard and R. Lassalle, EBU Review - Technical, August 1987, pp.168–190.

Finally, the signal is passed on to radio broadcast means 226.

A basic task of the control block 228 is to identify the component parts of the input data stream, for example destination information and other control information. This information, together with any information gained about the quality of the transmission channel, enables it to determine the degree of diversity that should be applied to the component parts of the data stream, and to schedule the transmission of data in appropriate time and frequency slots using an appropriate modulation scheme.

The control block 228 has available up to three adjustable dimensions which can be used to alter the behaviour of the system:

1. The number of bits in an input symbol, m. A symbol encoding

m bits has 2^m states.

2. The data block size, n_1. This can be no larger than N_1, the number of parallel output lines of the multiplexer 208.

3. The MCM symbol size, n_2, which is also equal to the number of carriers transmitted. This can be no larger than N_2, the number of parallel output lines of the multiplexer 214.

The choice of modulation scheme for the modulator 216 determines the required size of the input symbol m.

In most applications, the data block size n_1 will be an integer multiple of the MCM symbol size n_2. If $n_1 = k\, n_2$, one data block is transmitted over k MCM transmission periods. Hence, having $k>1$ makes time diversity available to the control block, since symbols that are separated by more than n_2 in the output from the demultiplexer 212 will be transmitted at different times. This is implemented by controlling the algorithm used by the interleaver 210.

Data supplied to different input lines of the IFFT block 220 appears modulated on a different carrier frequency on transmission (as described for example in "Multicarrier Modulation for Data Transmission: An Idea Whose Time Has Come", J. A. C. Bingham, IEEE Communications Magazine, May 1990, pp.5–14). Hence, the control block can implement frequency diversity by controlling the algorithm used by the interleaver 210 so that copies of data generated by the repeater 204 appear on different input lines to the IFFT block.

The receiver shown in Figure 3 receives a broadcast MCM signal and processes it to regenerate the bitstream provided as input to the transmitter. A radio reception means 302 generates a complex time domain waveform, from which the cyclic extension added by the transmitter is removed by a symbol recovery block 304. The waveform is then supplied as input to a multiplexer 306 which takes a portion of the waveform corresponding to the time taken to transmit one MCM symbol and splits it into N_2 samples, each of which is applied to one of its N_2 parallel output lines. A control block 326 can alter the block size so that the waveform is split into fewer than N_2 samples to correspond to the number of carriers actually transmitted.

The samples are then applied to a FFT block 308 to be fast Fourier-transformed, generating modulated data on each of its output lines. The data is demodulated by a symbol demodulator block 310 in which the method of demodulation is controlled by the control block 326 to correspond to that used in transmission. The output symbols (which may, of course, be corrupted by transmission errors) are then recombined into a serial stream by a demultiplexer 312.

A multiplexer 314 takes as input a stream of N_1 symbols and outputs each symbol onto one of its N_1 parallel output lines. The control block 326 can alter the block size to correspond to the data block size used for transmission. The output symbols are supplied to a de-interleaver 316 which reorders them and applies them to its output lines, under instruction from the control block 326 which uses the same algorithm as on transmission. The resultant set of symbols is recombined into a serial stream by a demultiplexer 318.

As with the transmitter, if $N_1=N_2$ the demultiplexer 312 and multiplexer 314 may both be omitted and the output from the demodulator 310 used directly as input to the de-interleaver 316.

If encryption was used on transmission, the serial symbol stream is processed by a decryption block 320.

Multiple copies of symbols that were generated and transmitted, using either frequency or time diversity, are now adjacent to one another in the serial symbol stream applied as input to a combiner 322. This block can use a variety of techniques to decide on the correct value for the symbol. As an example for Differential Phase Shift Keying (DPSK) with n copies of the data transmitted at the same time on different carriers, the combined complex symbol can be determined from

$$d(t) = Re\left[\sum_{i=1}^{n} g_i^2 x_i(t) x_i^*(t-1)\right] \qquad (1)$$

where Re(x) provides the real part of x, $x_i(t)$ is the received phasor from channel i at time t, $x_i^*(t-1)$ is the complex conjugate of the received phasor from the previous symbol and g_i^2 is a scaling factor chosen to optimise the decision. The received data is then determined by comparison of the phase of d(t) with one or more thresholds.

Finally, a converter 324 regenerates the required output bitstream from the stream of symbols passed to it, with the control block 326 ensuring that the conversion is appropriate for the symbols used.

To give further insight into the practical operation of a MCM system made in accordance with the invention, two examples will now be described.

The first example is for a high bit rate indoor communication system, such as WATM. It is assumed that the channel is stationary or slowly changing and that the input data is protected by channel coding, with codewords long enough to take advantage of the interleaving depth. Time diversity is unlikely to be effective. Parameters for this system are:

Number of carriers N_2= 16
Cyclic extension 2 samples
Effective sampling rate at transmitter = 20MHz
OFDM Symbol duration = 0.9 μ s
Modulation DQPSK, converter combines 2 bits into one symbol
Gross bit rate 2 x 16/0.9e-6 = 35.56Mbps

Consider three modes of operation. The appropriate mode is determined by examining the signal level and data quality for each carrier. The necessary signalling can be carried out (using a well protected channel) to establish the optimum mode of operation.

1. Under good conditions, with no significant multipath fading, no diversity is required. Data is transmitted at the gross bit rate (as modified by channel coding). Interleaving has no benefit so set N_1= N_2 . Blocks 210, 212 and 214 are not needed, and so could by bypassed to save processing power.

2. Under bad conditions frequency diversity is applied (to all data in this example). In this case all symbols are repeated once. Again set N_1= N_2 .

A fixed block interleaving is applied to separate the repeated symbols by $N_1/2$. In fact, no other re-arrangement of the symbol ordering is required. The transmission rate is reduced by a factor of two compared with the first mode of operation

The order of interleaved symbols could be $1,3,5,\ldots,N_1-1,2,4,6,\ldots,N_1$.

3. Under some conditions a fixed diversity separation will not be effective. An example of such a condition is where the channel transfer function in the frequency domain is periodic with a period equal to (or a multiple of) the diversity separation. This condition could occur, for example, where the channel contains two dominant propagation paths which happen to have a delay difference equal to the reciprocal of the diversity spacing (or a multiple of the reciprocal). In this case N_1 may be increased, for example to $N_1= 8\ N_2$. The interleaver 210 can be configured such that the diversity separations between the repeated symbols are unequal, and change between each of the OFDM symbols. The transmission rate is the same as that for the second mode of operation. The order of the first block of N_2 interleaved symbols could be as in the second mode of operation. If a cyclic shift is applied to part of the data the order of the second block could be: 1,3,5,7,9,11,13,15,6,8,10,12,14,16,2,4

The second example is for a mobile radio system. Here the channel may change rapidly, so that time diversity may be effective.

Consider first the downlink used for speech communication. The input data to the system consists of coded speech from different users multiplexed into a single data stream. As an example, assume that for each speech frame errors in some of the bits are less significant from the point of view of speech quality (for example the GSM full rate codec has this property). Channel coding is only applied to the most important bits.

Parameters of the speech codec are:

Bit rate = 8kbps

Fraction of important bits = 0.5

Code rate applied to important bits = 2/3

Bit rate of (coded) important bits = 6kbps

Bit rate of (uncoded) unimportant bits = 4kbps

Parameters of the transmission system are:

Number of carriers N_2= 512

Cyclic extension 100 samples

Effective sampling rate at transmitter = 20MHz

OFDM symbol duration = 30.6 μ s

Modulation DQPSK, converter combines 2 bits into one symbol

Gross bit rate 2 x 512/30.6e-6 = 33.46Mbps

This system could, in theory, support about 3300 voice channels. In this example the repeater 204 repeats once only the symbols containing coded important bits.

Consider first the downlink. Both time and frequency diversity could be applied to achieve resistance to multipath fading for moving terminals. Here both are considered. In this case $N_1 > N_2$, for example $N_1 = 8N_2$, and the interleaver 210 is configured such that the repeated bits are separated in time and frequency. In this example a 128x32 block interleaver would be suitable, except that the time and frequency domain spacing of the data would be uniform. Non uniform spacing can be achieved by cyclic shifting of parts of rows and columns within the 128x32 element matrix.

Now consider the uplink. Here the total bit rate will be much lower (i.e. speech from one user). For this and for various other practical reasons (such as reducing power consumption) it may be desirable to transmit using a limited number of adjacent carriers. The input stream may be padded with null data (at least conceptually), in which case the outputs from the modulator 216 will be zero, except for the desired carriers. The interleaver 210 would then be configured to produce a small number of symbol blocks (e.g. 2), separated in frequency by a defined spacing. The repeated symbols are placed in different blocks to achieve frequency diversity.

As an example, the speech codec might deliver data in 20ms frames of 100 symbols (200 bits including channel coding). After repetition of the important symbols this would become 160 symbols, which could be transmitted

in two groups of 80 symbols. The location of these groups of symbols in the frequency domain could change for successive frames.

From reading the present disclosure, other modifications will be apparent to persons skilled in the art. Such modifications may involve other features which are already known in the design, manufacture and use of radio communication systems and component parts thereof which may be used instead of or in addition to features already described herein.

Industrial Applicability

The present invention has a wide range of industrial applicability, including digital audio broadcasting, wireless ATM and future mobile radio systems.

CLAIMS

1. A method of operating a radio communication system using multicarrier modulation for transmission of data between two or more stations with one of said stations providing a data stream comprising a plurality of parts, characterised by applying different forms of diversity to at least two of said parts, the choice of diversity measures being made dynamically in response to the importance of the data or the quality of the transmission channel.

2. A method as claimed in claim 1, characterised by interleaving said parts and in that the interleaving algorithm is varied dynamically so that the frequency separation or time delay between transmitted copies of parts of a data stream varies with time.

3. A method as claimed in claim 1 or 2, characterised by varying dynamically the size of the output symbol so that the number of carriers transmitted varies with time.

4. A method as claimed in any one of claims 1 to 3, characterised by varying dynamically the size of the input data block so that the number of output symbols required to transmit one input data block varies with time.

5. A transmitter comprising conversion means for converting an input bitstream into symbols, repetition means for generating one or more copies of each input symbol, interleaving means for reordering the symbols in a data stream, modulation means for generating a data stream suitable for transmission over a radio channel, means for generating modulated carriers at multiple frequencies and transmission means, characterised in that means are provided for dynamically varying applied diversity measures in response to the importance of the data or the quality of the transmission channel.

6. A transmitter as claimed in claim 5, characterised in that encryption means are provided for generating an encrypted version of the symbol data stream.

7. A transmitter as claimed in claim 5 or 6, characterised in that means are provided for dynamically controlling the algorithm used by the interleaver so that the frequency separation or time delay between transmitted copies of parts of a data stream varies with time.

8. A transmitter as claimed in any one of claims 5 to 7, characterised in that means are provided for dynamically varying the size of the output symbol so that the number of carriers transmitted varies with time.

9. A transmitter as claimed in any one of claims 5 to 8, characterised in that means are provided for varying the size of the input data block dynamically so that the number of output symbols required to transmit one input data block varies with time.

10. A receiver comprising reception means for receiving signals at multiple frequencies, means for extracting modulated data from modulated carriers at multiple frequencies, demodulation means for extracting a data stream from the transmitted data, de-interleaving means for reordering the symbols in the data stream, combining means for generating one output symbol from one or more transmitted copies of a symbol and conversion means for generating an output bitstream from the symbol stream, characterised in that means are provided for dynamically varying applied diversity measures to correspond to those used for transmission.

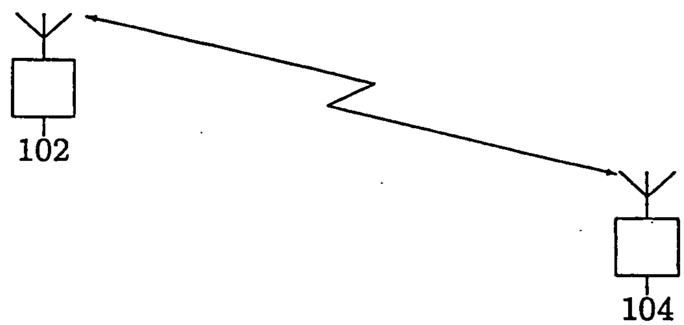

FIG. 1

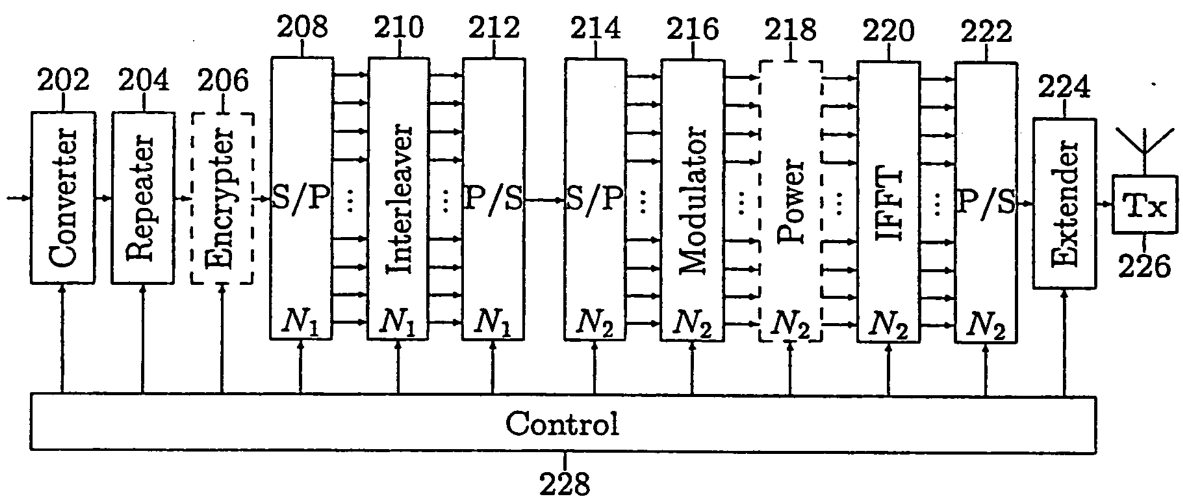

FIG. 2

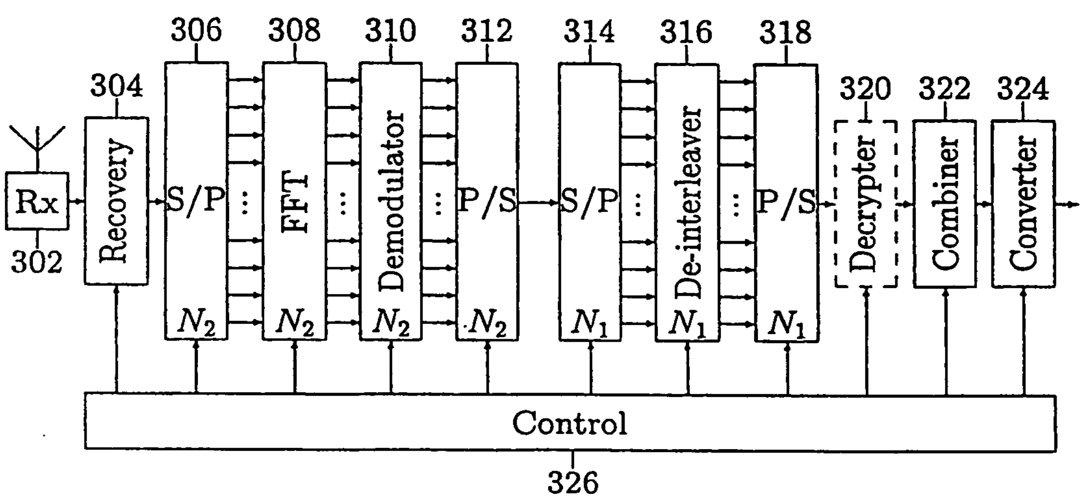

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 98/00913

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04B 7/02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04B, H04J, H03M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPIL, EDOC, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5283780 A (LEONARD SCHUCHMAN ET AL), 1 February 1994 (01.02.94), abstract --	1,5,6,10
A	GB 2291570 A (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.), 24 January 1996 (24.01.96), abstract --	1,5,6,10
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A	EP 0722227 (NEC CORPORATION), 17 July 1996 (17.07.96), see whole document -- --------	1-10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
21 August 1998	07-09-1998
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Malin Gullstrand Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Information on patent family members

27/07/98

International application No.
PCT/IB 98/00913

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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